# Coincidence spectroscopy

Studies of nuclear magnetic dipole transition probabilities and of positron annihilation lifetimes. Design and construction of an electron-electron coincidence spectrometer and its application to the investigation of some complex nuclear disintegrations

INAUGURAL DISSERTATION

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TOR RAGNAR GERHOLM
Fil. lic., Stockh.

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By due permission of the philosophical faculty
of the University of Uppsala, to be publicly discussed in the lecture hall
of the Institute of Physics on May 24, at 10 a.m., for the degree of
Doctor of Philosophy.

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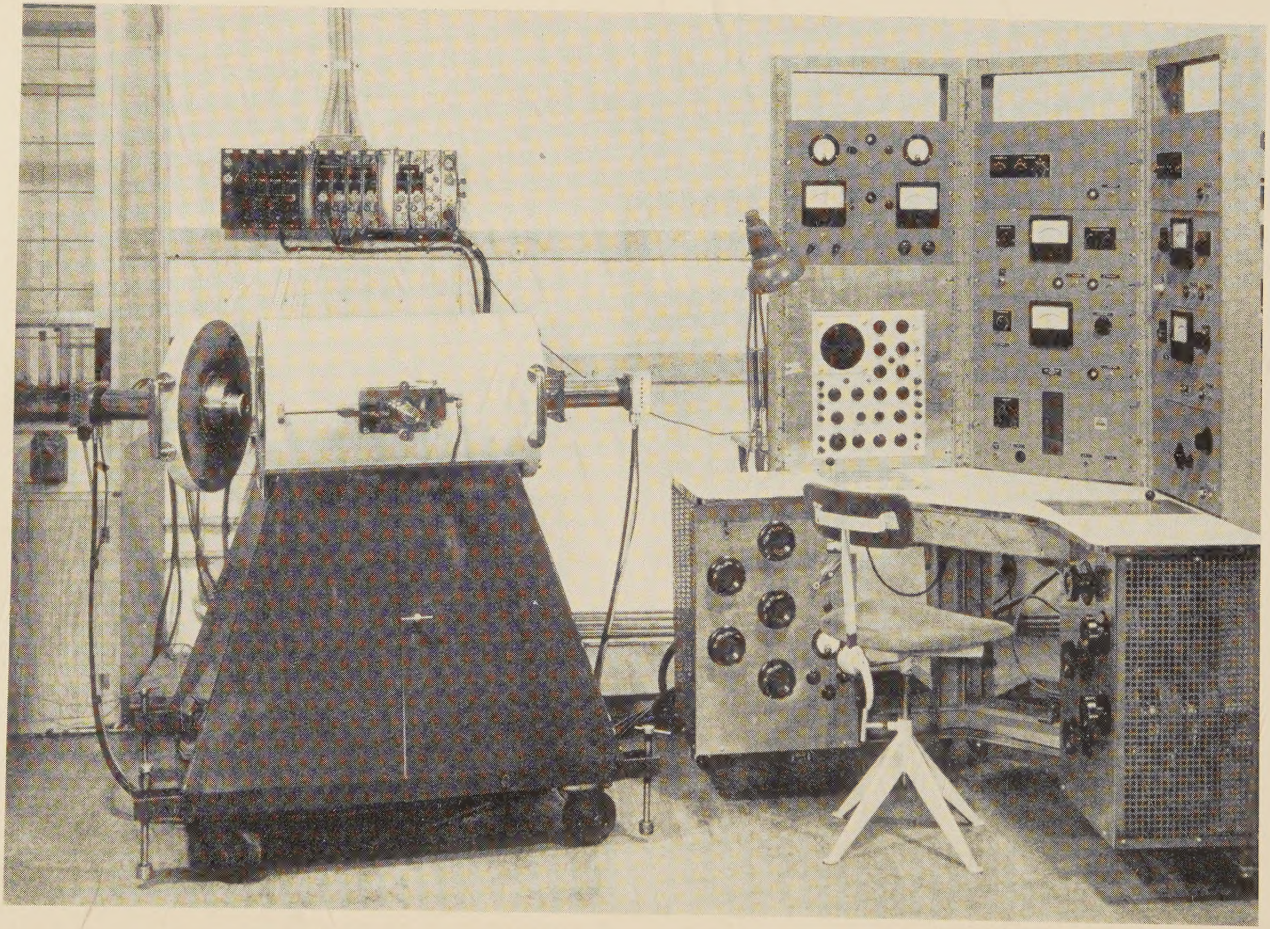

The coincidence spectrometer with its control table shown to the right.

# COINCIDENCE SPECTROSCOPY

*Studies of nuclear magnetic dipole transition probabilities and of positron annihilation lifetimes. Design and construction of an electron-electron coincidence spectrometer and its application to the investigation of some complex nuclear disintegrations*

By Tor Ragnar Gerholm

This paper gives a summary of the following five articles:

I. T. R. Gerholm: Beta-ray spectroscopes. *Encyclopedia of Physics* (editor S. Flügge), *Vol. 33*, 609 (1956).

II. T. R. Gerholm: High transmission coincidence spectrometer with good resolution. *Rev. Sci. Instr., 26*, 1069 (1955).

III. T. R. Gerholm: Studies of nuclear disintegrations with a coincidence spectrometer. *Arkiv f. Fys. 11*, 55, (1956).

IV. H. de Waard and T. R. Gerholm: Orbital momentum forbidden magnetic dipole transitions in some odd proton nuclei. *Nuc. Phys., 1*, 281 (1956).

V. T. R. Gerholm: On the annihilation of positrons in condensed materials. *Arkiv f. Fys. 10*, 523, (1956).

## PREFACE

The coincidence technique was first introduced by Bothe and Geiger in 1925. As is well known the general method is to use two (or more) different counters, arranged in such a way that they can detect, simultaneously and independently of each other, radiations emitted from the same source. The signals from these counters are fed to a coincidence circuit, which selects and transmits to the recording unit only those signals that arrive within a certain time interval of one another, "the coincidence resolving time". If this resolving time ($2\tau_0$) is short, the coincidence events are likely to have originated in the same nucleus—"genuine coincidences"—but since the signals from each counter are distributed at random, there will be some not actually in cascade that happen to be separated by a time interval less than the resolving time, and these will result in "chance coincidences" or "random coincidences".

It is easily seen that the ratio between genuine and random coincidences—i.e. the signal-to-noise ratio—will be proportional to $(2\tau_0 N_0)^{-1}$, where $N_0$ is the number of nuclear disintegrations per unit time. This implies that sometimes the genuine coincidence counting rate becomes inconveniently low, because the maximum source strength is limited by the required signal-to-noise ratio and by the resolving time of the coincidence apparatus. The most serious limitations encountered in the coincidence method are due to this fact. This is so, in particular, when G.M. counters serve as detectors, since the slow response of these counters results in long resolving time, and consequently only weak sources can be used.

These limiations, however, are to a great extent overcome by the development of scintillation detectors. Most suitable for coincidence work are the fast organic phosphors. With these detectors coincidence resolving times of a few millimicroseconds can be realized, which is two or three orders of magnitude shorter than can be achieved with G.M. counters. The past few years have seen a rapid development of the coincidence method which is now applied in many different ways to the study of elementary processes and nuclear disintegrations.

The term *coincidence spectroscopy* is used to denote that coincidences are recorded between particles or quanta of specified energies. This means that some sort of energy selection must be provided. Under favourable conditions this can be done in a simple way by the absorbtion method. The experiments reported in IV were all made in this way. It is sometimes possible to make use of the linear relationship between pulse height and energy absorbed in the scintillator. With a so-called fast–slow coincidence arrangement one can select out of all coincidence events only those that have fulfilled certain energy conditions, set by the differential discriminators in the side-channels. However, the energy resolution provided in this way is very low. This method was adopted in the study of the annihilation process reported in V.

For the investigation of complex nuclear disintegrations is it necessary to secure good energy resolution in both channels. For this purpose the electron-electron coincidence spectrometer described in II was built. In principle, this instrument consists of two long lens beta ray spectrometers placed end to end. It is sometimes desirable to study electron-gamma coincidences. The instrument was therefore later provided with a NaI(Tl) scintillation detector of special design. With this unit the instrument can easily be converted into an electron-gamma coincidence spectrometer. In III some different applications of current interest are discussed. Experimental results obtained in the study of some neutron-deficient isotopes are also given.

## SUMMARIES

I. T. R. Gerholm: Beta-ray spectroscopes. *Encyclopedia of Physics* (editor S. Flügge), *Vol. 33*, 609 (1956).

Theory and design of different kinds of beta-ray spectrometers and spectrographs and a review of their applications,

*Contents:*

1. Introduction
2. Fundamental principles of beta-ray spectroscopy
3. Flat spectroscopes
4. Lens spectroscopes
5. Comparison between different types
6. Electrostatic field spectroscopes.
7. High precision beta- and gamma-ray spectroscopy.
8. Experimental techniques.
9. Beta-ray spectroscopic technique applied to gamma-ray spectroscopy.
10. Coincidence spectrometers.
11. Appendix ($B\varrho$ versus keV tables).

II. T. R. Gerholm: High transmission coincidence spectrometer with good resolution. *Rev. Sci. Instr., 26,* 1069 (1955).

*Summary:*

An electron-electron coincidence spectrometer is described. Magnetic lenses are used for the energy selection in each channel, and the coincidence counting efficiency is increased by using long lens spectrometers. At an effective transmission of 3 %, relative half-widths of 1.3 % (source diameter 0.2 cm) and 3.1 % (source diameter 0.5 cm) were obtained. "Triangular field" focusing, introduced here, gives a favorable high luminosity in spite of small dimensions, distance between source and detector being only 25 cm in each half of the instrument. The focusing properties of this field form are discussed. Anthracene crystals cemented onto Lucite light guides serve as detectors, and it is shown that the light transmission efficiency of the guides can be considerably improved by machining them to a certain profile theoretically corresponding to 100 % light collection. In practice efficiencies of 70–60 % are obtained for Lucite light guides between 10 cm and 20 cm. The performance of the instrument is illustrated by some results obtained with coincidence measurements on the electron spectrum of $Pb^{200}$.

III. T. R. Gerholm: Studies of nuclear disintegrations with a coincidence spectrometer. *Arkiv f. Fys. 11,* 55 (1956).

*Summary:*

A spectrometer for electron-electron and electron-gamma coincidence measurements is described. Attention is called to some of its applications, namely (i) the study of complex nuclear disintegrations, (ii) determinations of internal conversion coefficients and branching ratios and (iii) measurements of the lifetimes of specified nuclear levels. The experimental difficulties and the limitations encountered are discussed in some detail. The instrument has been used for the study of the following isotopes: $Pb^{200}$, $Pb^{205}$ and $Tl^{200}$. Finally, a new method is suggested for the measurement of very shortlived nuclear levels ( $<10^{-10}$ sec.) with the aid of the electron-electron coincidence spectrometer and a high-frequency transmitter.

IV. H. de Waard and T. R. Gerholm: Orbital momentum forbidden magnetic dipole transitions in some odd proton nuclei. *Nuc. Phys., 1,* 281 (1956).

*Summary:*

The halflives of the following excited nuclear states have been measured with delayed coincidence techniques:

145 keV level in $Pr^{141}$: $T_{1/2} = (19 \pm 2) \times 10^{-10}$ sec
163 keV level in $La^{139}$: $T_{1/2} = (15 \pm 1) \times 10^{-10}$ sec
160 keV level in $I^{131}$: $T_{1/2} = (9 \pm 1) \times 10^{-10}$ sec
279 keV level in $Tl^{203}$: $T_{1/2} = (1.2 \pm 0.3) \times 10^{-10}$ sec

Theoretical points of view about these $l$-forbidden ($\Delta l = 2$, $\Delta j = 1$) M1 transitions are briefly reviewed and it is shown that the matrix elements derived from the experimental halflives are in reasonable agreement with expectations based on the spin-orbit coupling encountered in the shell model.

V. T. R. Gerholm: On the annihilation of positrons in condensed materials. *Arkiv f. Fys. 10*, 523 (1956).

*Summary:*

The positron annihilation lifetimes in various metals and insulators have been measured with an automatic millimicrosecond coincidence equipment. The lifetimes were found to be the same in all metals and equal to $(2.5 \pm 0.3) \times 10^{-10}$ sec, which is longer than the value hitherto accepted, $(1.5 \pm 0.3) \times 10^{-10}$ sec. The halflife of the first excited state in $Pb^{207}$ was found to be $(0.9 \pm 0.3) \times 10^{-10}$ sec. This result is in accordance with the value $1.0^{+0.4}_{-0.2} \times 10^{-10}$ sec deduced for this halflife from the reduced transition probabilities measured in Coulumb excitation. The annihilation lifetimes in various metals and insulators are in agreement with the theoretical values deduced from a model suggested here. A weak component with a longer lifetime has been observed in aluminium. An interpretation of this component is suggested, based on the same model.

## ACKNOWLEDGEMENTS

My first experience in nuclear physics dates back to 1943, when I had the favour of working for some summer months at the Nobel Institute of Physics in Stockholm under Professor Manne Siegbahn. Later I was introduced into nuclear spectroscopy by Professor Kai Siegbahn, under whose guidance I have been working first at the Nobel Institute, then for almost three years at the Royal Institute of Technology in Stockholm and, finally, for the last two years at the University of Uppsala. It is a pleasure for me to acknowledge here my sincery gratitude to Professor Kai Siegbahn for his keen interest in my work and for his generous help during these years.

To all those who have in different ways contributed to this work I am gratefully indebted. In particular I should like to thank Professor Per Ohlin and my collegues and friends at this institute.

The work was sponsored by the Swedish Atomic Energy Commission (Atomkommittén).

Uppsala in April, 1956

Tor Ragnar Gerholm
Physics Department, University of Uppsala